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Estimates of Maturing Rates and Masses at Maturity for Body Components of Sheep

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ABSTRACT: Weight data for fleece-free empty body, carcass and offal components, and their chemical constituents (protein, water, lipid, and ash) were collected via serial slaughter techniques. Rams sired by a sheep breed of high genetic merit for growth were slaughtered from birth through 48 mo of age. Approximately six rams were killed at each of 13 slaughter ages. The data were fit with a nonlinear function $Y_t = A(1 - Be^{-kt})$ to provide estimates of rates of maturing (k) and weight at maturity (A) for components of interest. Except for the testes, all tissues met the convergence criterion. The proportion of offal components relative to empty BW was greatest at birth and steadily declined after this time. Rates of maturing for visceral organs (except for the heart) and the protein constituent of the offal were of greater magnitude than the carcass and nonprotein constituents of both the offal and carcass. Estimated maturing rate and weight at maturity for lipid of the carcass exceeded corresponding estimates of the offal lipid. Evidence was provided suggesting that the developmental patterns of body components may be established by functional demand.

Key Words: Growth Curve, Carcasses, Viscera, Protein, Water, Lipids

Introduction

To facilitate investigations into allocation of limited resources in animal production systems, the activities for defined components of the production system require characterization. Included among these activities is the accretion of empty body tissues from birth through maturity of the animals. Information such as this can be used to develop predictive models of animal performance. These predictive models vary in the degree of complexity and scope. Independent data sets are needed to evaluate growth models.

Total weight of an animal is a static measure of the dynamic process of growth. It reflects the summation of the weight of the body constituents. Just as "growth curve" analyses can be used to characterize weight-age relationships for the total animal, this approach also may be used to characterize the increase in mass of body constituents. Although it is possible to record repeated measures on individual animals with the former measurement, limited opportunities exist for repeated observations from individual animals for the latter.

The objective of the present study was to characterize mature mass and maturing rates for empty body components and chemical constituents of rams from birth through 48 mo of age. Information is needed to allow estimation of parameters for individual constituents of empty BW from birth through maturity. These estimates are required to set parameters for models and(or) the information may be used for simulation model evaluation.

Materials and Methods

Male lambs produced from mating Columbia rams to crossbred ewes (1/2 Finnsheep, 1/4 Dorset, 1/4 Rambouillet) born during a 25-d period in March 1981 were assigned to the study. All lambs remained intact. Lambs were weaned at approximately 70 d of age. After a postweaning adjustment period, the rams were placed in a drylot and had access to a diet that contained 2.89 Mcal of ME/kg of DM and 16% CP. Animals were fed this diet for approximately 140 d, after which the lambs were transported to a ram holding facility. Rams remained at this facility until the time of slaughter. Weights of individual rams were recorded at birth, weaning, and at monthly intervals until the time of slaughter.

Table 1. Slaughter schedule for rams

Month	1981	1982	1983	1984	1985
January	—	6	—	—	—
March	6	6	6	6	7
June	6	—	—	—	—
July	—	6	—	—	—
September	6	—	6	6	—
November	6	6	—	—	—

(columns grouped under header: Year)

Six animals were killed at each time with the exception of the last slaughter when seven animals were sampled (Table 1). Slaughter data were collected from new born lambs within 24 h of birth. A sample of rams was slaughtered after weaning and at 70-d intervals through 12 mo of age.

After slaughter at 12 mo, the population continued to be sampled at 6-mo intervals; the final group was slaughtered at approximately 48 mo of age (Table 1). Rams chosen for slaughter at each slaughter event were identified as the individuals whose removal would have minimal effect upon the mean weight and variance of the remaining population. Rams identified for slaughter were not fed for 24 h. Rams were exsanguinated. Weights recorded on day of slaughter included live animal, pelt, pelt-free head, fore-hind hooves, carcass, and the abdominal and thoracic organs: liver, heart, lung, digesta-free gastrointestinal tract, spleen, kidneys, and testes. Fat deposits around the heart, lung, and gastrointestinal tissues were removed before weighing the organs. Except for the pelt and the carcass, the remaining components were pooled and frozen (−10°C) for storage. The carcass was partitioned and frozen for storage (−10°C) after these measurements were recorded. Two body pools for each animal, noncarcass and carcass, were subsequently ground four times and sampled in triplicate (approximately 100 g). All samples from the body pools were analyzed for DM, N, ether extractable lipid (fat), and ash following AOAC (1984) protocols.

Mature weights and maturing rates were estimated for live weight, pelt-free empty body, pelt-free head, fore-hind hooves, hot carcass, liver, heart, lung, kidney, pooled rumen-complex, testes and small and large intestines (empty gastrointestinal tract), total offal (all noncarcass tissue exception for fleece and blood), and the constituents for each body pool-protein (calculated N × 6.25), water, ether extractable lipid (fat), and ash. Parameter estimates for these traits were obtained by fitting weight-age data to a nonlinear function using the derivative-free method procedure available in SAS (1985). Parameters of the monomolecular growth function have been described in biological terms (Brody, 1945). Using least squares methods to solve the following nonlinear model: $Y = A(1 - Be^{-kt})$, parameter estimates for the asymptote (A, mature weight), shape of the curve (k, rate of maturing), and constant of integration (B) were obtained. Convergence was assumed when the difference in residual sums of squares between the $i^{th} - 1$ and the ith iteration relative to the ith iteration + 10^{-6} was < 10^{-8}. Initial estimates required for the nonlinear procedure were derived either from mean values at 48 mo for A or from published estimates for the organs for k (Brody, 1945). For chemical constituents of the carcass and offal depots, initial values for k were estimated as the rate of weight change during the period relative to the mean weight at 48 mo of age.

Results

Means and standard deviations for fore-hind hooves, pelt-free head, and internal organs are reported in Table 2. At birth, the structural components (sum of the pelt-free head and fore-hind hooves) represented 12.9% of the empty body, liver 4.5%, heart 1.2%, lung 4.3%, empty gastrointestinal tract 6.9%, and kidney 1.2%. At 48 mo, the proportions of these tissues relative to empty BW were structural 5.7%, liver 1.2%, heart .6%, lung 1.1%, empty gastrointestinal tract 6.2%, kidney .2%, and testes .8%. Precision of the scales was not sufficient to measure testes weight at birth. Means and standard deviations for live weight and body chemical constituents by mean slaughter age are reported in Table 3. Animals killed at birth had a mean weight of 5.4 kg (SD .71). The empty body was composed of 14% protein, 76.6% water, 4.8% fat, and 4.3% ash. Mean composition of the empty body for rams at the last slaughter was 15.7% protein, 48.5% water, 31% fat, and 5.1% ash.

The convergence criterion was satisfied for all components of interest except the testes. Inspection of a plot of the residuals from the traits did not provide an indication of bias in the fit of the model. Figures 1 and 2 are representative of smooth curves for empty BW and liver obtained by fitting the serial slaughter data to the nonlinear model. Observations for each slaughter event are included in the figures.

Asymptotic (mature weight, kilograms) and curve shaping parameter (rate of maturing, kilograms·kilograms⁻¹·day⁻¹) estimates for live weight, pelt-free empty body, carcass and offal weights, and chemical constituents are reported in Table 4. Mature weight for 1/2 Columbia rams was estimated as 106 kg, which was lower than the estimate reported by Blaxter et al. (1982) for 1/2 Suffolk rams. For rams in the present study, approximately 73% of estimated mature weight was represented by the pelt-free empty BW.

Among the carcass and offal chemical constituents, offal protein and water had the greatest rates of maturing. Estimates of maturing rates for the remaining traits were intermediate and similar. Rate of maturing of offal fat was lower than estimated rates of maturing for the other constituents (Table 4). For the

Table 2. Means and standard deviations for structural components and internal organs of rams by slaughter age from birth through 4 years of age[a]

Mean slaughter age, d	Structural			Organs				
	Fore-hind hooves, g	Head, g	Liver, g	Heart, g	Lung, g	Gastrointestinal tract, kg	Kidney, g	Testes, g
1	146 (103)	399 (164)	188 (168)	51 (27)	180 (115)	.29 (.17)	54 (38)	0 (0)
94	506 (130)	1,126 (193)	506 (136)	181 (95)	506 (139)	2.3 (.42)	106 (23)	91 (76)
166	743 (194)	1,705 (328)	1,025 (290)	218 (49)	762 (148)	3.2 (.63)	91 (32)	163 (183)
229	869 (109)	1,988 (317)	968 (218)	272 (40)	718 (259)	3.7 (.51)	136 (29)	453 (218)
292	884 (110)	2,215 (191)	876 (139)	310 (34)	718 (144)	3.7 (.68)	159 (25)	415 (78)
346	1,013 (136)	2,442 (198)	892 (210)	264 (105)	831 (311)	3.8 (.37)	151 (23)	386 (69)
473	948 (74)	2,915 (340)	1,103 (105)	346 (32)	777 (113)	5.0 (.41)	184 (21)	529 (86)
594	927 (94)	3,006 (197)	1,037 (143)	330 (64)	795 (71)	4.7 (.57)	175 (19)	547 (94)
709	1,138 (170)	3,286 (399)	1,147 (136)	374 (48)	1,008 (205)	5.4 (.59)	172 (29)	467 (70)
897	1,052 (83)	3,403 (385)	1,107 (116)	414 (47)	751 (89)	5.4 (.65)	178 (11)	751 (133)
1,081	1,165 (112)	3,591 (115)	945 (148)	408 (19)	1,223 (784)	4.8 (.48)	189 (16)	538 (74)
1,275	1,055 (40)	3,665 (298)	987 (69)	428 (46)	747 (85)	5.8 (.51)	194 (18)	745 (71)
1,444	1,187 (122)	3,521 (189)	1,009 (121)	476 (31)	878 (77)	5.6 (.64)	190 (10)	622 (192)

[a]Standard derivations in parentheses.

Table 3. Means and standard deviations for body components of rams by slaughter age from birth through 4 years of age[a]

Slaughter age, d	n	Weight at slaughter, kg	Pelt free empty body, kg	Carcass				Offal			
				Protein, g	Water, g	Fat, kg	Ash, g	Protein, g	Water, g	Fat, kg	Ash, g
	6	5.4 (.71)	4.2 (.72)	428 (81)	2,145 (250)	.1 (.01)	136 (30)	163 (66)	1,079 (462)	.1 (.01)	45 (19)
94	6	31.9 (9.8)	19.6 (7.1)	2,382 (850)	7,984 (3212)	2.4 (1.7)	806 (405)	825 (171)	4,220 (777)	.8 (.36)	219 (46)
166	5	52.1 (17.3)	37.1 (12.4)	4,410 (1225)	12,932 (3987)	8.4 (4.1)	1,421 (421)	1,243 (283)	6,016 (1336)	2.2 (1.2)	346 (72)
229	6	63.2 (11.7)	45.3 (9.7)	5,124 (887)	16,243 (2883)	10.6 (3.3)	1,777 (295)	1,348 (213)	6,312 (956)	3.7 (1.3)	386 (55)
292	6	73.7 (39.7)	53.4 (7.7)	5,936 (745)	18,541 (2973)	13.3 (2.7)	2,000 (201)	1,416 (160)	6,545 (742)	5.0 (.8)	428 (42)
346	6	74.9 (15.2)	56.1 (9.2)	6,330 (1048)	20,689 (4219)	13.0 (2.9)	1,960 (253)	1,540 (159)	6,955 (640)	5.5 (1.1)	461 (56)
473	6	81.9 (6.2)	57.9 (5.0)	7,586 (583)	22,600 (2073)	10.2 (1.7)	2,635 (338)	1,915 (123)	8,710 (533)	3.4 (3.5)	566 (104)
594	6	81.6 (9.1)	52.4 (6.7)	7,579 (660)	22,116 (2416)	6.6 (2.6)	2,705 (157)	1,841 (114)	8,333 (802)	2.3 (1.0)	551 (60)
709	6	103.4 (14.8)	64.0 (8.7)	8,464 (1012)	26,154 (3147)	10.7 (2.7)	2,921 (351)	2,117 (183)	9,034 (683)	3.8 (1.3)	717 (102)
897	6	107.2 (9.8)	78.8 (6.4)	9,258 (678)	27,096 (2109)	20.6 (2.8)	3,054 (366)	2,123 (206)	9,020 (583)	7.2 (1.0)	744 (188)
1,081	6	99.7 (12.6)	72.2 (9.1)	8,686 (1175)	28,858 (4767)	14.1 (4.9)	3,061 (483)	2,127 (126)	8,704 (737)	6.0 (1.9)	765 (82)
1,275	6	107.0 (6.2)	79.5 (6.5)	9,502 (479)	28,092 (1591)	19.1 (3.5)	3,290 (269)	2,199 (85)	9,112 (387)	7.5 (1.8)	787 (35)
1,444	7	110.9 (5.9)	81.8 (4.1)	10,606 (621)	30,899 (2018)	18.0 (1.2)	3,457 (230)	2,224 (172)	8,805 (712)	7.4 (.7)	763 (64)

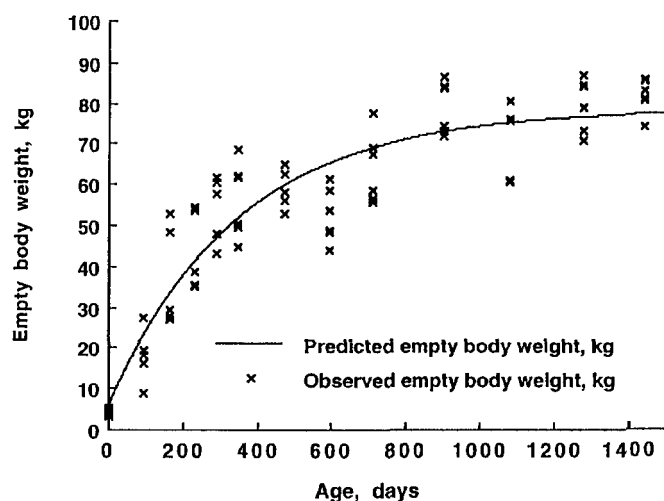[a]Standard deviations in parentheses.

Figure 1. Plot of observed empty body weights at designated ages of slaughter (xxx) and predicted growth curve resulting from fitting observations to Brody growth function (——).

Table 4. Parameter estimates (± standard error) characterizing growth of live weight, hot carcass, offal, and components of rams[a]

Component	A, kg		k (× 10^{-4})		B	
			Estimated parameters			
Live wt	106	± 1.4	3.23 ± .37		.95 ± .01	
Pelt free empty body	78	± 2.4	2.90 ± .33		.93 ± .04	
Carcass	60	± 2.0	2.77 ± .33		.93 ± .04	
Protein	9.5 ±	.07	2.51 ± .31		.95 ± .01	
Water	29.7 ±	.79	2.83 ± .29		.93 ± .03	
Fat	18	± 1.4	2.34 ± .65		.93 ± .08	
Ash	3	± .08	2.82 ± .25		.96 ± .03	
Offal total	18.8 ±	.48	3.40 ± .36		.92 ± .04	
Protein	2.2 ±	.04	3.63 ± .27		.91 ± .03	
Water	8.9 ±	.14	4.83 ± .39		.87 ± .03	
Fat	8.2 ±	1.2	1.38 ± .52		.95 ± .06	
Ash	.8 ±	.03	2.41 ± .28		.95 ± .03	

[a]Estimates from fitting growth equation $y_t = A * (1 - Be^{-kt})$ where: Y_t = weight at time t, t = days from birth, A = estimated weight at maturity of component, k = estimated rate of maturing of component (kilograms·kilograms^{-1}·day^{-1}), and B = integration constant.

remainder of the paper, comments regarding the relative mass of components or constituents relate to pelt-free empty body mass at maturity unless otherwise specified.

At maturity, 76.9% of the empty body was accounted for in the carcass component compared with 67.9% of the estimated weight at 1 d postpartum (5.7 kg empty BW, predicted weight). Relative to carcass weight at maturity, the chemical constituents of the carcass component were 15.8, 50.0, 30.0, and 5% for protein, water, fat, and ash, respectively. Relative to 1 d postpartum empty BW, the carcass constituent proportions were 8.8% protein, 39.6% water, 16.4% fat, and 3.1% ash. Relative proportions of estimated protein, water, fat, and ash of the carcass tended to increase as the animal approached maturity. Approximately 32.3% of the weight at 1 d postpartum was attributable to the offal component. Estimated protein (183 g, 3.2%) and water (1,194 g, 21.1%) at birth tended to be higher than constituent proportions of offal at maturity (2.6% protein, 11.4% water, respectively), whereas the proportions of fat (420 g, 7.4%) and ash (42 g, .7%) at 1 d postpartum were lower than those observed at maturity (10.5% fat and 1.2% ash).

Parameter estimates for the structural components of hooves and the pelt-free head and internal organs are reported in Table 5. Rates of maturing of the fore-hind hooves, liver, lung, kidney, and empty gastrointestinal tract were larger than the pelt-free head and heart.

Predicted weight of hooves at 1 d postpartum (140 g) represented approximately 2.4% of empty BW at that time compared with 1.4% at maturity. The proportion of pelt-free head decreased from 6.7% at 1 d

postpartum to 4.7.% at maturity. Proportion of internal organ tissue at maturity ranged from 1.3% for the liver to .2% for the kidney; heart and lung had values of .6 and 1.1%, respectively, and the empty gastrointestinal tract, 7.0%. Based on predicted weights at 1 d postpartum for liver (146 g), lung (187 g), kidney (55 g), and empty gastrointestinal tract (1.54 kg) the proportional weight of these organs relative to empty BW decreased from time of birth to maturity by 51, 67, 80, and 75%, respectively. The only organ whose developmental pattern tended to be similar to empty
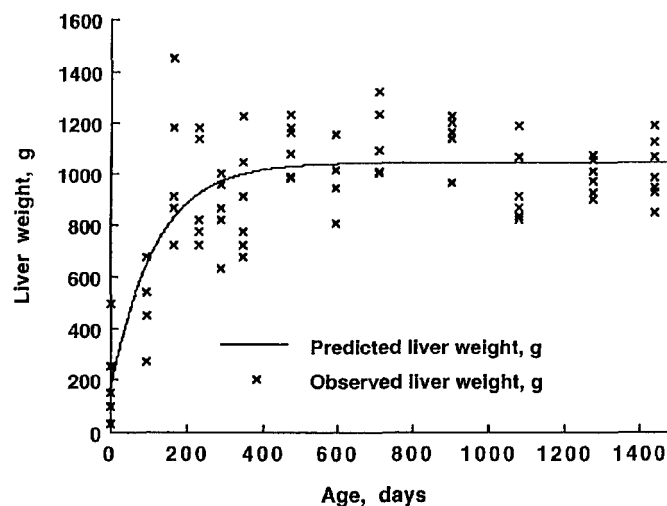

Figure 2. Plot of observed liver weights at designated ages of slaughter (xxx) and predicted growth curve resulting from fitting observations to Brody growth function (——).

Table 5. Parameter estimates (± standard error) characterizing growth of structural components and internal organs of rams[a,b]

Item	Estimated parameters		
	A	k (× 10⁻⁴)	B
Fore-hind hooves	1,101 ± 22	5.48 ± .59	.88 ± .04
Pelt free head	3,667 ± 68	2.95 ± .21	.90 ± .02
Organs			
Liver	1,041 ± 27	8.47 ± .15	.86 ± .07
Heart	447 ± 17	2.63 ± .40	.82 ± .04
Lung	892 ± 49	6.51 ± 2.13	.79 ± .13
Kidney	185 ± 4	5.53 ± .85	.70 ± .05
Empty gastro-intestinal	5.43 ± .12	4.23 ± .41	.92 ± .04

[a]Estimates from fitting $y_t = A * (1 - Be^{-kt})$ where: Y_t = weight at time t, t = days from birth, A = estimated weight at maturity of organ, k = estimated rate of maturing of organ (kilograms·kilogram⁻¹·day⁻¹), and B = integration constant.

[b]Units for A: kilograms for empty gastro-intestinal, grams for remainder of components.

BW was the heart, which tended to sustain the relative proportion at each of these time points (81 g and 1.5% at birth vs 447 g and 1.1% at maturity).

Discussion

The fit of the three parameter model was satisfactory. As discussed by Doren et al. (1989), the goodness-of-fit characteristics of nonlinear models containing more parameters may be superior to the model used in the present paper, but the appropriate model is best defined by the nature of the data and application of the results. In this regard, the primary objective of the present study was to obtain estimates of mature masses of the components of empty BW and some measure of rate of accretion of these components.

Characterization of growth and development of empty body components typically is accomplished through imposition of treatments (Blaxter et al., 1982). Limited information is available characterizing growth patterns through maturity of empty body constituents for a breed of sheep previously characterized as having high genetic merit for postweaning growth (Leymaster and Smith, 1981). Maturing patterns for carcass and noncarcass components were consistent with information previously reported by researchers studying the allometric relationships among body components or constrained forms of the allometric relationship to allow estimation of relative maturing rates with a linear model (Butterfield, 1988). Estimates of maturing rates (k) for liver, lung, and kidney and the structural component of fore-hind limbs were two- to threefold greater than the estimate for the carcass. Brody (1945), Kirton et al. (1972), and Butterfield et al. (1983) reported allometric coefficients significantly < 1 when log values of these

components were regressed on the log of empty BW. Butterfield (1988) provided similar rankings for these tissues pattern of development but with coefficients > 1 because of application of the linear form of a prediction equation. Tissues essential for life process (i.e., respiration and metabolism) would be expected to be highly developed at birth, whereas tissues associated with locomotion and storage would be lesser developed, and tissues associated with reproduction would be among the latest maturing tissues. In the present study, the only tissue that did not meet the convergence criterion was the testes. Developmental patterns of tissues seem to be set to meet a priority of growth described as a functional demand by Bryden (1969).

Of interest in the present study was the developmental pattern of the liver, an early maturing tissue based on the estimated k value. This observation agrees with the allometric coefficient estimate reported by Brody (1945). Taylor and Murray (1993) reported a nonlinear relationship between mass of liver and proportion of mature weight attained (degree of maturity). Using the relationship derived by these researchers, predicted liver weight based on the estimated mature pelt-free empty BW (A) was in close agreement with the estimated liver weight at maturity in the present study; 1,148 vs 1,041. However, a comparison at .60 mature mass was not as satisfactory. The relationship reported by Taylor and Murray (1993) predicted a liver mass of 689 g. Predicted liver mass based on the parameters estimated in the present study was 912 g and occurred at approximately 229 d of age. Work reported by Koong et al. (1982) and Ferrell (1988) provides evidence that the liver tissue is sensitive to energy intake. Observations for liver mass in the present study through 229 d of age were obtained from rams provided a high level of nutrition since weaning. The discrepancy between the two predictions of liver mass seems to support the conclusion of Taylor and Murray (1993) that a relationship between liver mass and degree of maturity is affected by the intake of energy.

The kidney, lungs, and gastrointestinal tract were similar to the liver in rates of maturing in that they were relatively high. This becomes critical when the relationship between mass of the visceral organs and energy expenditure is considered (reviewed by Ferrell, 1988). These tissues make up < 20% of the empty body but the metabolism of these tissues constitutes approximately 40 to 45% of total expenditure of energy by the animal (Ferrell, 1988). At 229 d, liver, lung, kidney, and the empty gastrointestinal tract constitute approximately 47% of the offal component of the lamb. The rate of maturing for offal protein was approximately 45% greater than the rate of maturing for protein in the carcass. Leymaster and Jenkins (1985) reported that for rams of similar genetic merit for growth, > 80% of the variation in ADG between 32 and 73 kg could be explained by the accretion rates of

offal and carcass protein ash and lipid. Using path analysis, they reported that the constituents having the largest direct effects on ADG were accretive rates of carcass and offal protein. Although the visceral protein component of empty BW was approximately threefold less than the carcass protein component of the empty body (2.8 vs 10.0%), the larger direct path coefficient was associated with offal protein accretion.

Changes in feeding programs during the period of high growth impetus may influence the developmental pattern of these tissues resulting in variation in energy requirements for maintenance, thus influencing feed conversion efficiency (Turner and Taylor, 1983). A protocol to increase postweaning performance (growth, weights at given age, etc.) and carcass merit by the livestock industry through breeding and nutrition programs requires that the interrelationships among specific organs and other tissues be considered.

Implications

Simulating accretion of components of empty body mass requires that the predictive equations, whether the equations are formulated from mechanistic concepts or derived from empirical relationships, to be sensitive to both genetic and environmental sources of variation. Allocation priorities adopted to partition ingested nutrients within simulation models should reflect biological relationships among constituent parts. The early rates of maturing of portal drained viscera organs and liver coupled with their association with higher rates of energy expenditure and influence on average daily gain need to be considered. Adoption of feeding standards that reflect the dynamic nature of nutrient utilization is required by the industry.

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